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HAARP 2011 SUMMER STUDENT RESEARCH CAMPAIGN

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16 October 2012

Final Report

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14. ABSTRACT
The 2011 Summer Student Research Campaign (SSRC) was conducted at the High Frequency Active Auroral Research Program (HAARP) Research Station in Gakona, Alaska during the period 18–27 July 2011. The SSRC included 26 students and mentors representing 11 universities and federal research laboratories. The program included daily meetings to provide a forum for reporting results and discussion of individual experiments and included a daily scientific presentation or tutorial. Scientific topics addressed experimentally included studies of Stimulated Electromagnetic Emission, F-region Artificial Field-Aligned Irregularities, effects of scintillation on GPS signals, studies of the Extremely Low Frequency (ELF) generation region and of methods for improving conversion efficiency, and the incorporation of sophisticated modulation techniques to improve the quality of ionospherically generated ELF communication signals using QPSK and error correction.

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Ionosphere, Ionospheric modification, Ionospheric irregularities, Ionospheric optical emissions, Ionospheric scintillation, HAARP, Simulated Electromagnetic Emissions

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Preface and Acknowledgements

The HAARP 2011 Summer Student Research Campaign was conducted at the HAARP Gakona Facility over the period 18 - 27 August 2011. The campaign was scheduled as an opportunity for university graduate students to visit the HAARP facility and become familiar with using it for research purposes by planning, executing and reporting on experiments of their own design. The format of the activity required that each student be assisted by a mentor. Nine operational days were included in order to take advantage of a wide variety of background ionospheric conditions and to provide ample time for each student to investigate variations within their experiment plan. The campaign period also included daily meetings at which tutorials or presentations were provided by a mentor or other visiting scientist. Students were encouraged to provide interim results of their experiments during these daily meetings.

We would like to acknowledge the participation of each of the mentors and other visiting scientists who provided tutorials and daily consultative guidance to the students. We also want to acknowledge the HAARP facility's staff and the transmitter system operators. The often complex and sophisticated transmitter and antenna beam operations and frequent experiment revisions required expertise and dedicated effort that was greatly appreciated by all participants. We particularly recognize the efforts of the following individuals who set up each of the experiments and operated the transmitter and antenna array during the campaign.

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Dr. Mike McCarrick	Chief Scientist and operator
Dr. Helio Zwi	Software engineer and operator
David Seafolk-Kopp	Software engineer and operator
Ben Uscinski	Software engineer and operator

We also gratefully acknowledge the significant time and effort invested by Dr. Brenton Watkins of the Geophysical Institute who operated the HAARP Modular UHF Ionospheric Radar during the campaign.

Less visible but equally as important to the campaign's success were the contributions by the site support staff who provided support services, transmitter and diagnostic maintenance and assisted individual researchers in equipment set up data retrieval. The 100% availability of the transmitter system during this campaign was a direct result of the work invested by the following staff members and we are grateful for their contributions:

Marty Karjala	HAARP Site Manager
Deana Rietveld	HAARP Admin Assistant
Jay Scrimshaw	HAARP Senior Electrical Engineer
Travis Million	HAARP Power Engineer
Tracy Coon	HAARP Associate Electrical Engineer
Dave Coon	HAARP Associate Electrical Engineer
Stef Scribner	HAARP Maintenance Technician
Josh Geldersma	HAARP Maintenance Technician

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1. Background: The 2011 HAARP Summer Student Research Campaign

From 2000 until 2008, the High Frequency Active Research Program (HAARP) and the National Science Foundation (NSF) sponsored an annual learning and research program in Alaska for graduate level students lasting ten days to two weeks. The goal of this program, called the Polar Aeronomy and Radio Science (PARS) Summer School, was to acquaint university students with many of the scientific facilities located in Alaska and to provide an introduction to conducting research at the HAARP Research Station in Gakona, Alaska. The Summer School was planned and conducted jointly by HAARP and by the University of Alaska Fairbanks (UAF) and was split into two segments. The first portion of the school was held at UAF and included a series of targeted lectures along with visitations to scientific facilities in the Fairbanks area including the UAF Poker Flat Research Range (PFRR). The Summer School then moved to Gakona, Alaska for a short, four-day research campaign at the HAARP Research Station. While at HAARP, students would consult with their mentors or with other visiting scientists to plan and execute experiments of their own design while cooperating with the facility operators to learn the high power transmitter's capabilities and limitations and learning to use the facility's suite of diagnostic and scientific instruments. The duration of the research portion of the PARS Summer School was long enough to permit short experimentation periods for each student participating in the program.

Beginning in 2009, the timing for the traditional PARS Summer School was changed to a biennial schedule to relieve the workload for UAF personnel who planned or participated in the activity. In the intervening years, a new program called the Summer Student Research Campaign (SSRC) was conducted to retain the opportunity for students to participate in a research campaign at HAARP albeit without the concentrated lecture period at UAF. The main focus of the SSRC is to expose university students to the capabilities of the HAARP facility by having them develop, conduct and report on individual research experiments while acting as a Principal Investigator (PI) in a campaign-type atmosphere. Increasingly, students at many universities have returned several times to HAARP during the yearly PARS or SSRC activity to continue and expand on research begun during their first year, usually as part of their doctoral program.

The SSRC expands on the PARS Summer School by providing a significant increase in facility operational time. This has advantages in several areas including permitting the design of more exhaustive investigations and reducing the impact of one day's unfavorable background geomagnetic conditions by making available multiple opportunities to conduct experiments.

The increased time at HAARP has also engendered the development of group participation in experiment development in the way experiments were conducted at the early ionospheric interaction facilities at Arecibo and EISCAT. Each day, at the daily meeting, students are asked to present a briefing on their experiment including its goals, procedures and expected results. The group (students and mentors) is encouraged to ask questions and comment on the approach taken. Students are also given the chance to present interim results at these daily meetings and the group is again encouraged to offer suggestions on improving the experiment. More will be said about the daily activities in a later section.

The second biennial SSRC was planned and organized for the HAARP program by NorthWest Research Associates (NWRA) and was conducted at the HAARP Research Station during the period 18 – 27 July 2011. A goal of 80 hours was set for total campaign time which would allow in excess of 3 hours per participant over the 8 day period.

2. Overview of the HAARP Summer Student Research Campaign

The decision to proceed with planning for the 2011 SSRC was made during a mid-May teleconference with personnel form AFRL, NRL and NWRA and a preliminary timetable was established. An announcement soliciting interest would be sent immediately to previous SSRC and PARS participants and to professors at universities participating in HAARP research through grants and contracts with the expectation that the announcement would be distributed further throughout the community. At the time of the teleconference, the availability of fuel to support the campaign was still an uncertainty, but a tentative goal of 80 hours of operational time was established

The announcement was distributed and although it was not a firm commitment to the activity it did request potential experiment descriptions by 25 May 2011 and indicated that a decision to go ahead with the campaign would be made by 3 June along with notification that each responder's experiment had been accepted or rejected. At this time, a special SSRC 2011 web site was set up using the HAARP web server. The SSRC web site was populated with information on the preparation and submission of information required to visit the HAARP facility, information on how to prepare a research proposal for HAARP, and additional supplementary information.

At this time, the UAF was contacted to determine their availability and willingness to assist with certain administrative aspects of the program as they had during the SSRC 2009 including arranging for and reimbursing some student expenses associated with travel to the HAARP facility, subject to a fixed budgetary allotment.

A total of 23 proposals were received in response to the announcement. The proposals were reviewed by a committee consisting of the HAARP program managers and NWRA scientists. Because all of the proposals were sound and scientifically interesting and because the number received would permit over 3 hours of operational allocation to each experiment, all of the submissions were accepted. The proposers were notified of acceptance by e-mail on 5 June 2011 and instructions were provided on how to proceed with making travel arrangements through the UAF.

The instructions for proposal preparation included a request that any special frequencies needed for the experiment be specified in the submission. The proposals were examined carefully to determine frequencies not within the HAARP Research Station permanent frequency allocation. As in previous campaigns, several experiments were focused on examining Stimulated Electromagnetic Emission (SEE) or F-region Artificial Field-aligned Irregularities (AFAI), both of which exhibit unusual or enhanced effects when the operating frequency is close to a multiple of the electron gyrofrequency of approximately 1.45 MHz. Although the 2nd gyroharmonic is covered by the existing HAARP permanent frequency allocation, all higher harmonics are not. Therefore, the HAARP program manager was asked to request a temporary authorization from the regional frequency management office at Elmendorf AFB, to include these special frequencies. Table 1 is a listing of the frequency allocations that were in effect during the 2011 SSRC.

Table 1. Frequency Allocations for the HAARP Research Station in Effect During the 2011 SSRC

2650-2850 kHz *	
2850-3050 kHz	(Temporary)
3155-3400 kHz	
4040-4438 kHz	(Temporary)
4438-4650 kHz	
4750-4995 kHz	
5005-5450 kHz	
5450-5700 kHz	(Temporary)
5730-5950 kHz	
6765-7000 kHz	
7300-8100 kHz	
9040-9995 kHz **	

* Equipment limitations apply to frequencies below 2.7 MHz
** Equipment limitations apply to frequencies above 9.6 MHz

2.1 Considerations for the Schedule Development

Development of the campaign schedule was based on several factors including requests for specific times associated with satellite passes, requests for specific dates in order to accommodate travel plans, or the availability of specific diagnostic instruments, or requirements for specific ionospheric conditions. Each of these factors is discussed in greater detail in the following sections.

<u>Satellite Passes</u>

The development of a campaign experiment schedule always begins with penciling in all of the relevant satellite passes discussed in the proposals. In previous campaigns, student interest areas included experiments involving satellites in low earth orbit (LEO); however, for the SSRC 2011, there were no such requests and only Global Navigation Satellite System (GNSS) satellites were mentioned. (GNSS satellites include United States Global Positioning System (GPS) and the Russian GLONASS satellites.) Unlike LEO satellites whose orbits are characterized by short duration overhead passes, GNSS satellites are above the horizon for durations measured in hours and the times of interest for experimental purposes are dependent on the satellite moving into certain regions of the sky (e.g., near magnetic zenith). Typically, this favorable signal path geometry only lasts for 20 to 30 minutes. For SSRC 2011, GPS satellite receivers were set up on diagnostic pad 3 at the HAARP facility and at a nearby location just off site. The GNSS proposal provided predictions of the times when the required geometry would be satisfied. On any given day there were a sufficient number of acceptable GNSS “passes” to allow some degree of flexibility in scheduling these experiments consecutively with other, non-satellite dependent experiments.

Ionospheric Conditions

In contrast to previous PARS and SSRC activities, the 2011 campaign took place during the rising phase of the solar sunspot cycle. Therefore, solar activity was expected to be moderate (SSN>50) producing relatively high ionospheric densities. (The actual International Sunspot Number for July 2011 was 43.9 and the Smoothed Sunspot Number was 57.2.) When combined with the seasonal characteristics of the high latitude ionosphere, this resulted in several advantages for scheduling and conducting experiments: (1) Higher ionospheric density yields higher F-region critical frequency (f_oF2) which, in turn, allows greater use of the entire HAARP frequency allocation, (2) The availability of higher HAARP operating frequencies means that greater Effective Radiated Power (ERP) can be used in the experiments, (3) Greater ionization density combined with small solar depression angles after sunset (in the summer at high latitudes), means the critical frequency remains high late into the evening.

The success of many of the experiments was dependent on specific ionospheric conditions. For a large number of the experiments, operation at a frequency at or just below the F-region is essential. To assist in the schedule development, a prediction of F-region critical frequency f_oF2 was prepared using the ITS78 ionospheric model. The prediction was made for two levels of sunspot number, SSN = 50 and SSN = 75. Figure 1 shows the results of this prediction. (For comparison, the observed variation of f_oF2 as a function of time for each of the days during the SSRC campaign is given in Figures 16 and 17 in the Appendix).

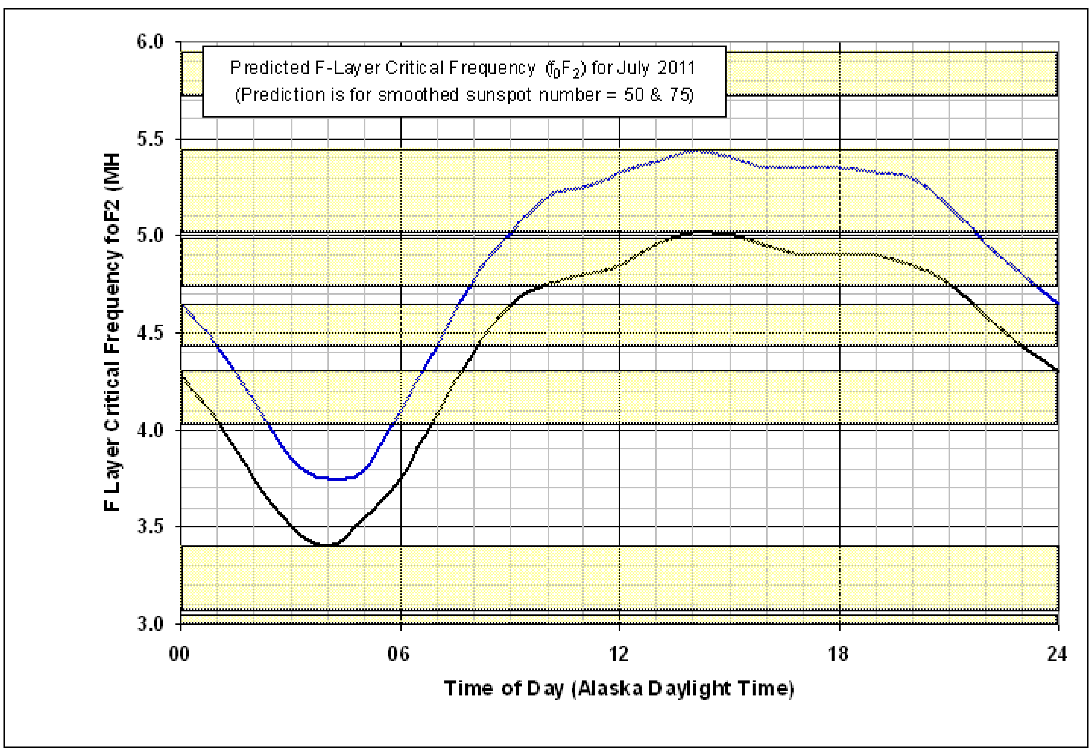


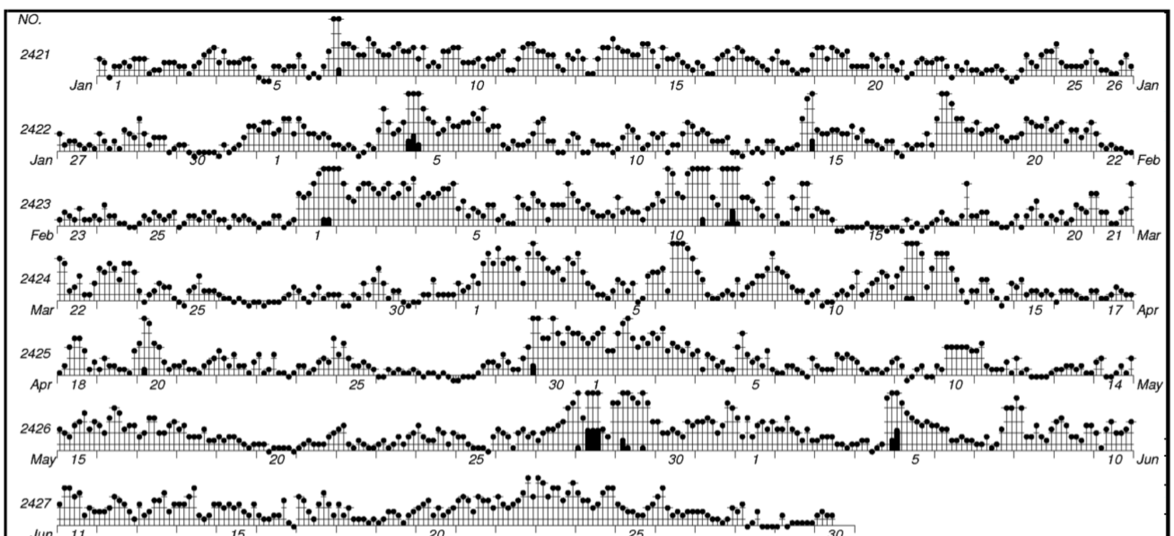
Figure 1. Prediction of F-region critical frequency (f_oF2) as a function of time of day (in Alaska Daylight Time) for July 2011. Yellow horizontal bands indicate frequency allocations in effect during SSRC11.

Several observations can be made from Figure 1. First, as a consequence of the higher point in the sunspot cycle and correspondingly greater ionospheric density along with long daylight hours in Alaska during the summer, f_oF2 never drops below the lowest available HAARP operating frequency, thus providing confidence in scheduling F-region experiments at any time of day, subject to specific experiment requirements.

For example, some of the experiments depended on being able to operate the HAARP transmitter at or just below f_oF2. For these experiments, it is not possible to continuously track the falling critical frequency after about 01:00 Alaska Daylight Time (ADT) because f_oF2 enters a forbidden frequency band. In addition, Figure 1 shows that those experiments requiring operation at the third gyroharmonic (approximately 4.2 MHz) may not be possible between the hours of 00:00 – 07:00 ADT.

One of the students participating in previous PARS/SSRC campaigns had been investigating E-region Field Aligned Irregularities using the Cornell VHF Radar located in Homer, Alaska. The E-region reaches its maximum ionization around local noon and this has added the scheduling complexity of providing mid-day and evening operations during the same campaign day. This student did not participate in SSRC 2011 with the result that day/night scheduling conflicts were not an issue.

Eleven of the proposers requested that their experiment be scheduled during times of the day when the auroral electrojet is most likely to be present in order to maximize the likelihood of good ELF generation. The occurrence of an overhead auroral electrojet is correlated with disturbed ionospheric conditions driven by solar activity and quantified by the planetary K_p index. A review of the K_p record for several solar cycles prior to the Summer School experimentation period (see Figure 2) showed recurrent disturbed conditions (high K_p) at a point in the solar rotation that would correspond with at least a portion of the campaign.



Jun	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	01	02	03	04	05	06	07	Jul
Jul	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	01	02	03	Aug

Figure 2. Planetary K_p recurrence diagram for six solar rotations prior to the SSRC 2011 experimentation period (shown in yellow).

Recurring disturbances are usually typical of a persistent coronal hole and a review of the coronal hole history for several solar rotations prior to the campaign period does reveal this pattern for a reappearing transequatorial coronal hole (designated CH446, CH450 and CH457 in the immediately preceding solar rotations). A review of conditions actually observed during the campaign (for example, see Figure 7 in the Appendix) shows disturbed conditions during the period 18-23 July due to coronal hole CH466 which is the reappearance of the same transequatorial coronal hole.

Through many years of operations at HAARP, it has been observed that under moderate geomagnetic conditions, the most productive hours for ELF generation are those just prior to local magnetic midnight. During this time period, the auroral oval (and coincident electrojet) is north of, but moving toward HAARP as the earth rotates the magnetic pole toward the longitude of HAARP. Generally, absorption is low as the electrojet moves southward over the HAARP facility (evidenced by low riometer absorption and an increasing, positive H magnetic field component shown on the magnetometer). For higher K_p, these events generally take place earlier in the evening. For very high K_p or at later times, the auroral oval may move to the south of HAARP (as evidenced by a negative magnetic field H component indicating a westward electrojet current) and there is a greater likelihood of increased absorption due to auroral precipitation, with the result that ELF signal generation may decrease. Therefore, ELF generation experiments requiring an electrojet are generally scheduled for the hours just prior to the closest approach of the auroral oval (21:00 – 02:00 ADT). Because of the large number of requests for time when the auroral electrojet is most likely to occur, the 2011 SRC campaign schedule was set up to include these late evening hours. The daily campaign start time was driven by experiments requiring f_oF2 to be above 4.2 MHz to permit investigation of SEE or AFAI effects at the 3rd gyroharmonic. As discussed previously, conditions favoring a high enough critical frequency for these experiments had to be scheduled prior to 00:00 ADT.

Based on the Kp recurrence chart, the bulk of ELF experiments were scheduled at the beginning of the campaign. In reviewing results of the ELF experiments conducted during the campaign, this turned out to be a very good scheduling decision.

Operator Endurance and Facility Limitations

The scientists, engineers and technicians who operate the HAARP transmitter and supporting infrastructure are dedicated personnel who, nevertheless, have endurance limitations. Typically, the facility can be operated for periods of 10 to 12 hours before the operators require a break. In addition, some equipment failures can be expected in normal operation and the site personnel require transmitter down times measured in hours in order to bring the facility back to full capability. The fuel budget established for this campaign limited the total number of campaign hours to approximately 80 and spreading those hours over the 9 campaign days resulted in daily operations well-within operator and facility endurance limits.

Special Schedule Requests

The students and mentor from MIT and Boston University requested that their experiments (S01 through S05) be scheduled prior to 23 July in order to meet a previously scheduled campaign assignment at the Arecibo Observatory in Puerto Rico. The schedule was adjusted accordingly for these experiments. However, it was not possible to provide the full quota of hours to all of these experiments since they also required special geomagnetic conditions.

One experiment (S09) was run as a probe to determine if special and unique ionospheric conditions were present. The probe was generally scheduled at or near the beginning of the hour, lasting for one minute. If the desired conditions were present, the schedule would be interrupted and the full special experiment would be run. Unfortunately, the desired conditions were not observed at any time during the 2011 SSRC campaign.

Availability of Diagnostic Instruments

The two main diagnostic instruments requested in the proposals were the HAARP Modular Ionospheric Radar (MUIR) and the SuperDARN facility located on Kodiak Island, AK. The MUIR, which is located on-site at the HAARP facility, is operated by the UAF/GI for all research. The MUIR was requested for nearly all of the F-region experiments and for many of the ELF experiments. The UAF scientist who operates MUIR during campaigns was able to be present at the site from 18-25 July. Experiments requiring MUIR were scheduled to coincide with those dates.

SuperDARN was requested by those experiments investigating F-region SEE or AFAI. In general, assignment of individual experiment (also termed "discretionary") time from SuperDARN requires submission of the request 90 days in advance. Because of the late decision to conduct the 2011 SSRC, it was not possible to meet this SuperDARN lead time requirement. However, a discretionary time block was in the SuperDARN schedule beginning 22 July at 16:00 ADT through the end of the campaign. Prior to that date, SuperDARN managers were able to provide 1 minute scans on a per-request basis. Finally, the special "HAARP mode" (one beam position dedicated to HAARP but with time-gate and integration limitations tied to the primary user) was available for the whole campaign period.

Students from MIT and Boston University brought a new instrument to this campaign to support their experiment and set it at the HAARP facility's most distant diagnostic pad. This instrument, called the Geomagnetic Observatory System (GMOS) is capable of measuring very small fluctuations in the geomagnetic field.

Two other groups brought specialized instruments which were installed at locations away from the HAARP facility. A new digital HF receiver was set up by scientists from the Naval Research Laboratory and used by the students from Virginia Tech at a location approximately 8 miles southwest of the HAARP facility. Students from the University of Florida installed four ELF receivers at geographically dispersed locations.

2.2 Final SSRC Experiment Schedule

Combining all of the operational and environmental constraints lead to the development of a fixed 9 to 9.5 hour daily schedule beginning near 17:00 ADT (01:00 UTC) and ending between 02:00 and 03:00 ADT (10:00 - 11:00 UTC). This schedule encompassed two GNSS satellite "passes" which had desirable signal path geometries and which repeated 4 minutes earlier each day of the campaign. The schedule included late afternoon ionospheric conditions characterized by stable and high f_oF2 to support SEE and AFAI experiments. And the daily schedule included late evening / early morning hours when there was a greater likelihood of an auroral electrojet for ELF experiments. The final schedule also contained two special experiments requested by the AFRL program managers.

Figure 3 is a high-level, conceptual representation of the schedule as actually executed. The campaign day and time are given in Universal Time (UTC) with the local time (ADT) along the right side. Times are given in 15 minute increments to save space; however, experiment start and stop times were defined with a resolution of 1 minute.

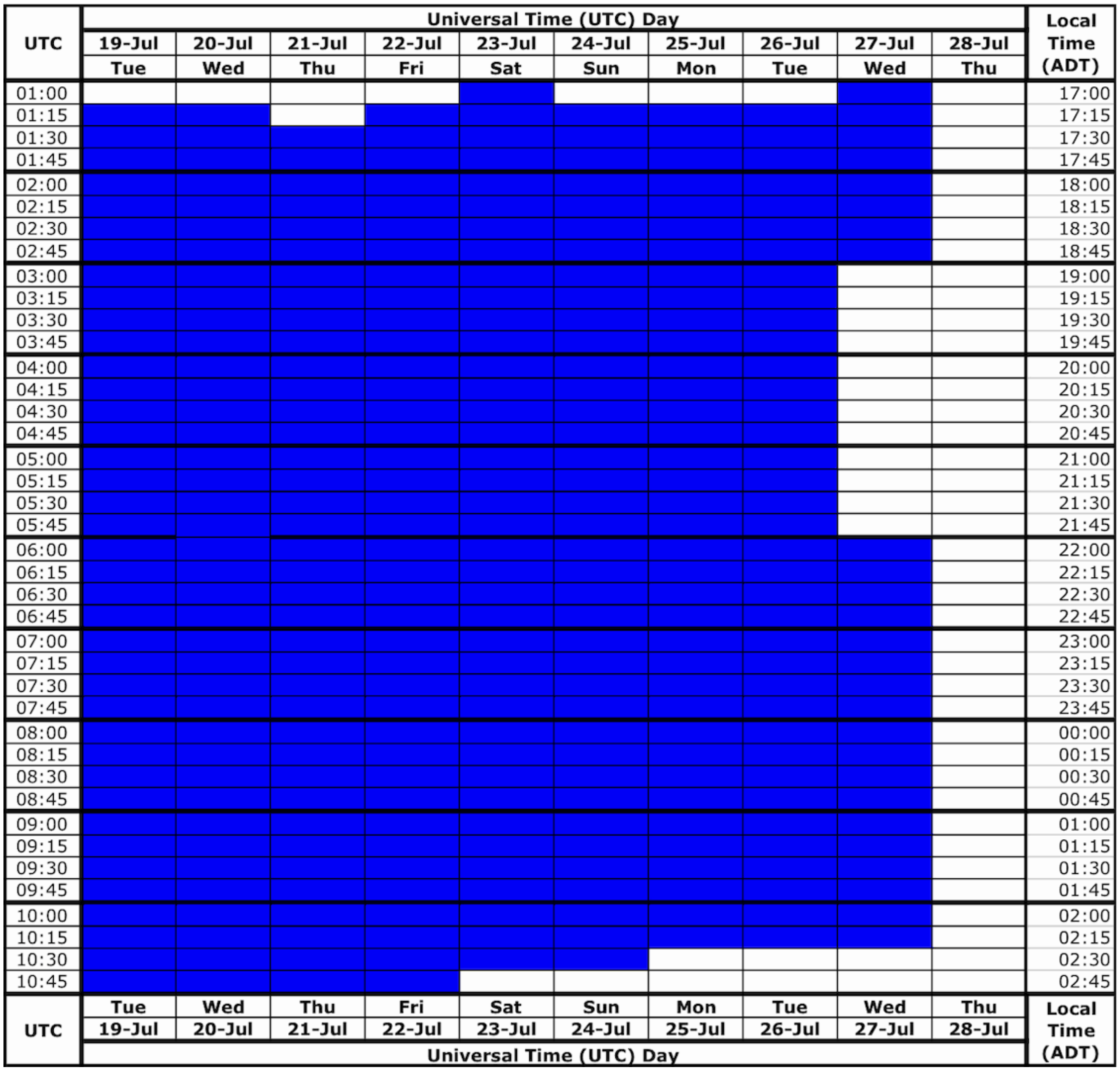


Figure 3. Conceptual operation schedule for the SSRC 2011. The blue shaded area shows the time allocated for experiments on each of the experimental days at the HAARP Research Station.

Table 2 is a listing of all of the experiments as executed during the 2011 PARS SSRC. The table shows the date and time that the experiment was conducted, the assigned experiment number and the name of the principal investigator.

Table 2. HAARP 2011 SSRC Research Schedule as Executed

Date UTC	Start UTC	Stop UTC	Experiment Number	Principal Investigator
7/19/2011	01:15:00	02:10:00	S23	Triplett
	02:15:00	02:54:30	S06	Balmer
	03:00:00	03:25:00	S23	Triplett
	03:30:00	05:29:30	S01	Pradipta
	05:30:00	05:59:30	S18	Agrawal
	06:00:00	06:01:00	S09	Harid
	06:02:00	06:59:30	S02	Dahlbom
	07:00:00	07:01:00	S09	Harid
	07:02:00	07:29:30	S04	Markwith
	07:30:00	07:59:30	S05	Rooker
	08:00:00	08:29:30	S17	Wang
	08:30:00	08:59:30	S18	Agrawal
	09:00:00	09:01:00	S09	Harid
	09:02:00	09:29:30	S12	Carpenter
	09:30:00	09:31:00	S09	Harid
	09:32:00	09:59:30	S08	Jin
	10:00:00	10:01:00	S09	Harid
	10:02:00	11:01:30	S22	Bordikar
7/20/2011	01:05:00	01:55:00	S23	Triplett
	02:00:00	02:01:00	S09	Harid
	02:05:00	02:49:30	S06	Balmer
	02:50:00	03:25:00	S23	Triplett
	03:30:00	04:29:30	S02	Dahlbom
	04:30:00	05:29:30	S03	Tooke
	05:30:00	05:59:30	S18	Agrawal
	06:00:00	06:01:00	S09	Harid
	06:04:00	06:29:30	S15	Fujimaru
	06:30:00	06:59:30	S12	Carpenter
	07:00:00	07:01:00	S09	Harid
	07:02:00	07:29:30	S04	Markwith
	07:30:00	07:59:30	S05	Rooker
	08:00:00	08:01:00	S09	Harid
	08:02:00	08:29:30	S11	Zoghzoghy
	08:30:00	08:31:00	S09	Harid
	08:31:30	08:59:30	S08	Jin
	09:00:00	09:01:00	S09	Harid
	09:02:00	09:29:30	S14	Webb
	09:30:00	09:33:30	S24	Kuo *

Table 2. HAARP 2011 SSRC Research Schedule as Executed (continued).

Date UTC	Start UTC	Stop UTC	Experiment Number	Principal Investigator
7/20/2011	09:34:00	09:59:30	S14	Webb
	10:00:00	10:01:00	S09	Harid
	10:02:00	11:01:30	S19	Mahmoudian
7/21/2011	01:20:00	01:50:00	S23	Triplett
	01:57:00	01:58:00	S09	Harid
	02:00:00	02:44:30	S06	Balmer
	02:45:00	03:15:00	S23	Triplett
	03:25:00	04:25:00	S01	Pradipta
	04:30:00	05:29:30	S02	Dahlbom
	05:30:00	05:59:30	S13	Jacobs
	06:00:00	06:01:00	S09	Harid
	06:02:00	06:59:30	S21	Fu
	07:00:00	07:01:00	S09	Harid
	07:04:00	07:29:30	S15	Fujimaru
	07:30:00	07:59:30	S18	Agrawal
	08:00:00	08:01:00	S09	Harid
	08:04:00	08:29:30	S15	Fujimaru
	08:30:00	08:59:30	S13	Jacobs
	09:00:00	09:01:00	S09	Harid
	09:01:30	09:29:30	S08	Jin
	09:30:00	09:59:30	S11	Zoghzoghy
	10:00:00	10:01:00	S09	Harid
	10:02:00	11:01:30	S20	Samimi
7/22/2011	01:20:00	01:45:00	S23	Triplett
	01:51:00	01:52:00	S09	Harid
	01:55:00	02:50:00	S06	Balmer
	02:51:00	02:52:00	S09	Harid
	03:03:00	03:53:00	S03	Tooke
	03:54:00	03:55:00	S09	Harid
	03:56:00	04:55:30	S22	Bordikar
	04:57:00	04:58:00	S09	Harid
	04:59:00	05:29:00	S04	Markwith
	05:30:00	05:59:30	S05	Rooker
	06:00:00	06:59:30	S21	Fu
	07:01:00	07:02:00	S09	Harid
	07:02:30	07:29:30	S05	Rooker
	07:30:00	07:59:30	S11	Zoghzoghy

Table 2. HAARP 2011 SSRC Research Schedule as Executed (continued).

Date UTC	Start UTC	Stop UTC	Experiment Number	Principal Investigator
7/22/2011	08:00:00	08:01:00	S09	Harid
	08:02:00	08:29:00	S17	Wang
	08:30:00	08:59:30	S11	Zoghzoghy
	09:00:00	09:01:00	S09	Harid
	09:02:00	09:29:30	S13	Jacobs
	09:30:00	09:59:45	S24	Kuo *
	10:00:00	10:01:00	S09	Harid
	10:02:00	10:32:00	S10	Naqvi
	10:33:00	11:03:00	S12	Carpenter
7/23/2011	01:00:00	02:13:00	S02	Dahlbom
	02:15:00	02:44:30	S03	Tooke
	02:45:00	03:53:00	S16	Langston
	03:54:00	03:55:00	S09	Harid
	03:56:00	04:56:00	S20	Samimi
	04:57:00	04:58:00	S09	Harid
	04:59:00	05:59:30	S05	Rooker
	06:00:00	06:01:00	S09	Harid
	06:01:30	06:29:30	S12	Carpenter
	06:30:00	06:59:30	S17	Wang
	07:00:00	07:01:00	S09	Harid
	07:01:30	07:29:30	S05	Rooker
	07:30:00	07:59:30	S14	Webb
	08:00:00	08:01:00	S09	Harid
	08:03:00	08:32:00	S15	Fujimaru
	08:33:00	09:02:30	S17	Wang
	09:04:00	09:05:00	S09	Harid
	09:06:00	09:36:00	S10	Naqvi
	09:37:00	10:04:54	S11	Zoghzoghy
	10:08:00	10:09:00	S09	Harid
	10:10:00	10:40:00	S12	Carpenter
7/24/2011	01:10:00	01:35:00	S23	Triplett
	01:45:00	02:34:00	S06	Balmer
	02:35:00	03:00:00	S23	Triplett
	03:10:00	03:55:00	S06	Balmer
	03:56:00	03:57:00	S09	Harid
	03:58:00	04:58:00	S19	Mahmoudian
	04:59:00	05:00:00	S09	Harid
	05:00:30	05:29:30	S16	Langston
	05:30:00	05:59:30	S13	Jacobs

Table 2. HAARP 2011 SSRC Research Schedule as Executed (continued).

Date UTC	Start UTC	Stop UTC	Experiment Number	Principal Investigator
7/24/2011	06:00:00	06:01:00	S09	Harid
	06:01:30	06:29:30	S08	Jin
	06:30:00	06:59:30	S10	Naqvi
	07:00:00	07:01:00	S09	Harid
	07:01:30	07:29:30	S13	Jacobs
	07:30:00	07:59:30	S14	Webb
	08:00:00	08:01:00	S09	Harid
	08:01:30	08:59:30	S12	Carpenter
	09:00:00	09:01:00	S09	Harid
	09:01:30	09:29:30	S11	Zoghzoghy
	09:30:00	10:14:45	S24	Kuo
	10:16:00	10:17:00	S09	Harid
	10:18:00	10:48:00	S10	Naqvi
7/25/2011	01:10:00	01:40:00	S23	Triplett
	01:50:00	02:29:30	S06	Balmer
	02:30:00	03:00:00	S23	Triplett
	03:05:00	03:45:00	S06	Balmer
	03:46:00	03:47:00	S09	Harid
	03:48:00	04:48:00	S20	Samimi
	04:49:00	04:50:00	S09	Harid
	04:51:00	05:21:00	S16	Langston
	05:23:00	05:52:00	S15	Fujimaru
	05:53:00	05:54:00	S09	Harid
	05:55:00	06:55:00	S22	Bordikar
	06:56:00	06:57:00	S09	Harid
	06:58:00	07:27:30	S17	Wang
	07:29:00	07:58:30	S18	Agrawal
	08:00:00	08:01:00	S09	Harid
	08:03:00	08:32:00	S15	Fujimaru
	08:33:00	09:02:30	S17	Wang
	09:04:00	09:05:00	S09	Harid
	09:06:00	09:36:00	S10	Naqvi
	09:40:00	10:24:45	S24	Kuo *
7/26/2011	01:00:00	01:04:01	S25	Bernhardt *
	01:10:00	01:30:00	S23	Triplett
	01:35:00	02:24:00	S06	Balmer
	02:25:00	02:55:00	S23	Triplett
	02:56:00	02:57:00	S09	Harid

Table 2. HAARP 2011 SSRC Research Schedule as Executed (continued).

Date UTC	Start UTC	Stop UTC	Experiment Number	Principal Investigator
7/26/2011	02:58:00	03:58:00	S19	Mahmoudian
	03:59:00	04:00:00	S09	Harid
	04:01:00	05:03:00	S21	Fu
	05:04:00	05:05:00	S09	Harid
	05:06:00	05:51:00	S16	Langston
	05:52:00	05:53:00	S09	Harid
	05:55:00	06:24:30	S06	Balmer
	06:25:00	06:54:30	S18	Agrawal
	06:56:00	06:57:00	S09	Harid
	06:58:00	07:28:00	S10	Naqvi
	07:29:00	07:59:00	S08	Jin
	08:00:00	08:01:00	S09	Harid
	08:02:00	08:31:30	S14	Webb
	08:33:00	09:03:00	S11	Zoghzoghy
	09:04:00	09:05:00	S09	Harid
	09:06:00	09:35:30	S18	Agrawal
	09:37:00	10:21:45	S24	Kuo *
7/27/2011	01:00:00	01:30:00	S23	Triplett
	01:36:00	01:37:00	S09	Harid
	01:38:00	02:07:45	S24	Kuo *
	02:08:00	02:11:30	S09	Harid
	02:12:00	02:25:30	S24	Kuo *
	02:30:00	02:55:00	S23	Triplett
	02:56:00	02:57:00	S09	Harid
		--- BREAK ---		
	05:54:00	06:24:00	S16	Langston
	06:25:00	06:39:30	S12	Carpenter
	06:40:00	06:55:00	S14	Webb
	06:56:00	06:57:00	S09	Harid
	06:58:00	07:59:30	S08	Jin
	08:00:00	08:01:00	S09	Harid
	08:02:00	08:32:00	S08	Jin
	08:33:00	09:03:00	S14	Webb
	09:04:00	09:05:00	S09	Harid
	09:07:00	09:36:00	S15	Fujimaru
	09:37:00	10:23:45	S24	Kuo *

* Additional experiment, not a part of the SSRC11 research group.

Twenty-four unique experiments (including the two special experiments) were conducted during the campaign. There were 26 students present during the campaign along with 13 mentors or visiting scientists representing 11 universities or research laboratories. The total operations time including standby periods was 83.2 hours. The total time allocated to students was 77.5 hours which provided an average time per student experiment of approximately 3.5 hours. Figure 4 shows the proportion of campaign time by experiment as a percentage of the total operations time during the SSRC 2011 campaign. The Triplett experiment represented three students and the Balmer experiment represented two students.

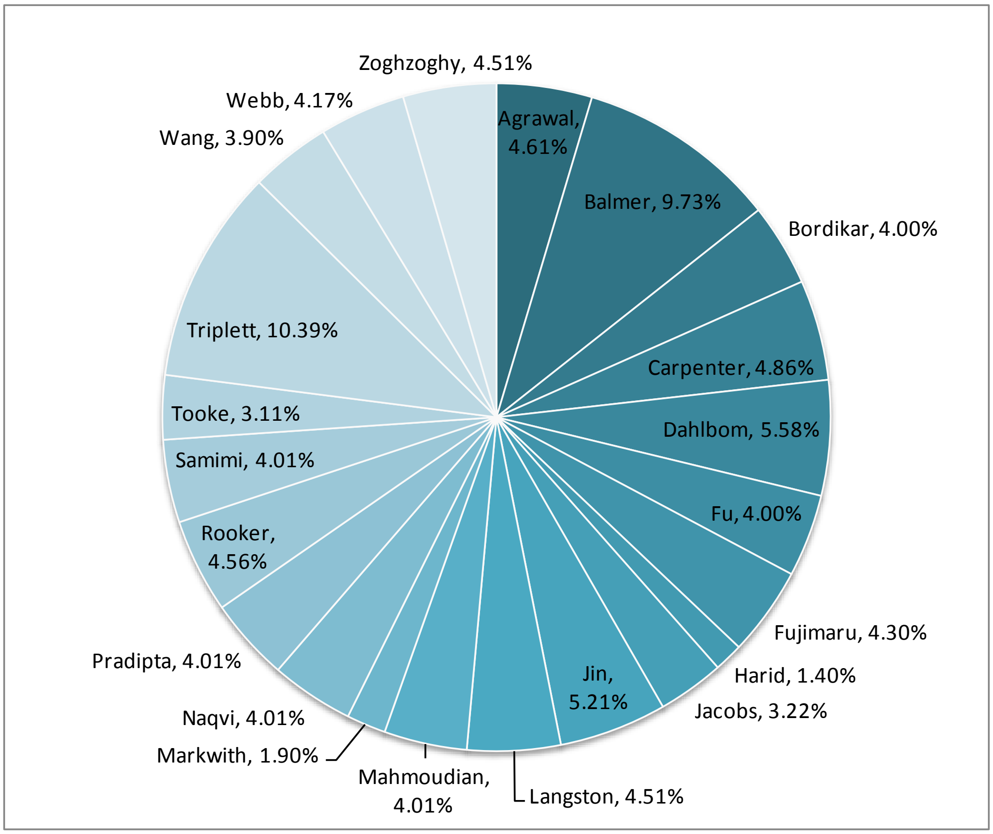


Figure 4. Division of total available campaign time by Principal Investigator for the 2011 HAARP SSRC.

Figure 5 shows the proportion of campaign time by participating university as a percentage of the total operations time during the SSRC 2011 campaign. A photograph of some of the PARS Summer School participants, taken during a tour of the HAARP high power transmitter and phased antenna array, is shown in Figure 6. Not all of the students were available for this photograph.

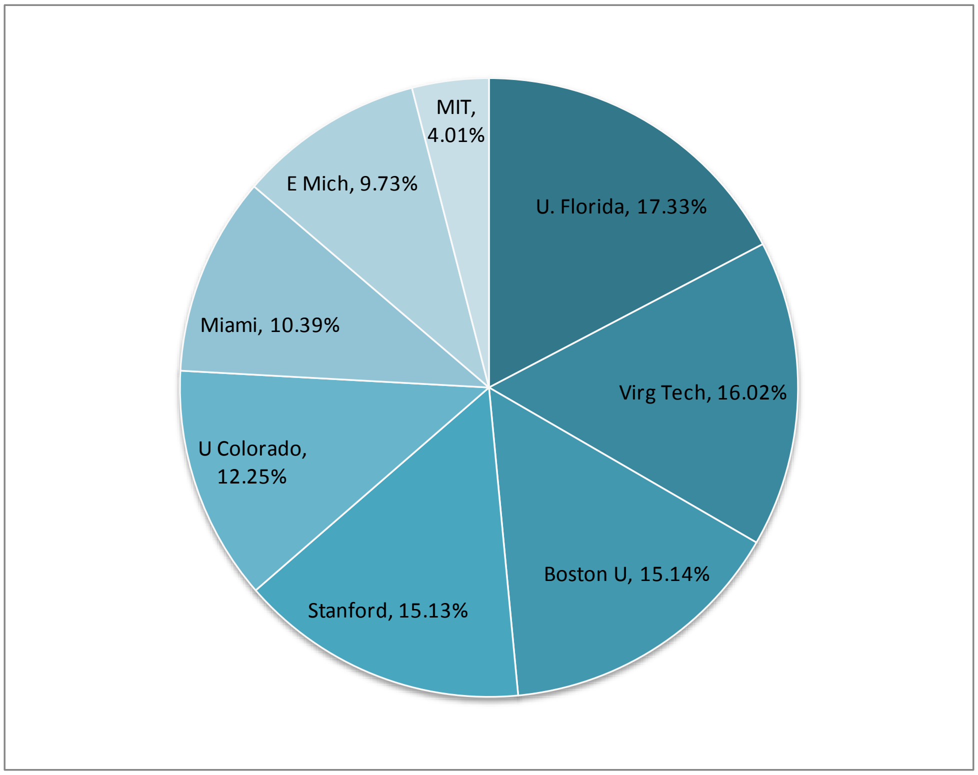


Figure 5. Division of total available campaign time by University participating in the 2011 HAARP SSRC.

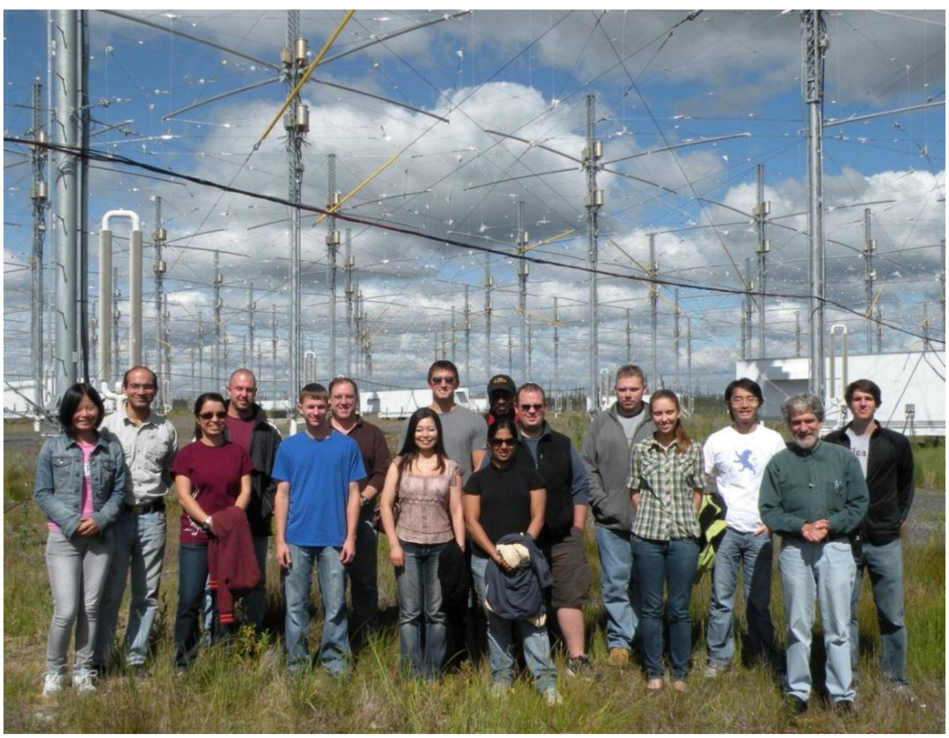


Figure 6. Some of the participants in the HAARP 2011 Summer Student Research Campaign standing in front of the HF transmitter and antenna array.

2.3 Daily Group Meetings

The traditional PARS Summer School is comprised of a week of lectures and tutorials at the UAF/GI in Fairbanks followed by a research period at the HAARP Facility. In order to retain the valuable learning aspect of the summer school, the daily activity schedule for the SSRC included a meeting consisting of a repeating agenda designed to promote group interaction along with a daily lecture presented by one of the visiting scientists or mentors. The daily meetings followed the standard format of:

- Review of Geomagnetic / Space Weather Conditions
- Facility Operational Status Update
- Review of Prior Day Experiments
- Experiment Plans for Current Day
- Lecture or Tutorial

The daily meeting began with a comprehensive review of prior day and predicted geomagnetic and space weather conditions, presented by a site scientist for the purpose of planning or modifying the current day experiment schedule. This was followed by an operational update providing information on the status of the HAARP transmitter and on-site diagnostic instruments. Students (or mentors) were then given the opportunity to present quick-look results of their prior-day experiments to the group. Those who were scheduled to conduct experiments on the current day were then polled to confirm that they were prepared and that their equipment, if any, was ready. The daily meeting concluded with a presentation provided by a visiting scientist or mentor on a subject relevant to ionospheric interaction or on the use of the instruments at the HAARP facility. On the last day of the campaign, each student was requested to give a short presentation on their experiment including a discussion of the initial goals, the experimental procedures used and preliminary results obtained, if possible.

Table 3 provides a summary of the SSRC program including lecture titles and presenter, for each day of the SSRC.

Table 3. HAARP 2011 SSRC Daily Meeting and Lecture Schedule.

Day	Lecturer	Lecture Title
July 18	E. Kennedy	Welcome & Introduction to HAARP and the Campaign
July 19	J. Morton	Ionospheric Effects on GNSS
July 20	M-C Lee	Large Scale Ionospheric Plasma Turbulence Caused by HAARP
July 21	A. L. Snyder	The New HAARP Digisonde
July 22	P. Bernhardt	Neutral Breakdown and Plasma Waves
July 23	M. Cohen N. Bunch	VLF/ULF Natural Radio Emissions Observable on the Ground
July 24	J. Sheerin	Langmuir Turbulence During Ionospheric Heating
July 25	W. Scales	Polar Mesospheric Summer Echo Heating Experiments
July 26	All Students	Experiment Summary Presentations

3. Student Experiments Summaries

All principal investigators were asked to submit quick-look reports in a standard format describing the research objective, the procedure or observation technique, and preliminary results. Submission of the reports was requested within six weeks of the end of the campaign. All of the student participants and several PIs for the special experiments submitted the requested reports. Although some investigators reported that there was insufficient time to analyze the data, many of the students were able to show significant results. The titles of these quick-look reports are listed here, along with the authors. The experiment numbers, shown in parenthesis at the end of the titles, correspond to those used in Table 2. All of the submitted quick-look reports are published in *Kennedy et al.,* 2012.

Generation and Diagnoses of Acoustic Gravity Waves at HAARP (S01)

> R. Pradipta and M-C. Lee (Mentor), *Massachusetts Institute of Technology, Cambridge, MA*; K-P. Hu, L. Rooker, D. Dahlbom, E. Markwith, and A. Tooke, *Boston University, Boston, MA*

Generation of Micropulsations Using Two HF Heater Waves (S02)

> K-P. Hu, L. Rooker, D. Dahlbom, E. Markwith, and A. Tooke, *Boston University, Boston, MA*; R. Pradipta and M-C. Lee (Mentor), *Massachusetts Institute of Technology, Cambridge, MA*

Investigation of HF Wave-induced Ionospheric Ducts (S03)

> R. Pradipta and M-C. Lee (Mentor), *Massachusetts Institute of Technology, Cambridge, MA*; A. Tooke, K-P. Hu, L. Rooker, D. Dahlbom, and E. Markwith, *Boston University, Boston, MA*

Spectral Evolution of HF Heater-induced Ion Lines (S04)

> L.M. Ross, E. Markwith, K-P. Hu, L. Rooker, D. Dahlbom, A. Tooke, *Boston University, Boston, MA*; R. Pradipta and M-C Lee (Mentor), *Massachusetts Institute of Technology, Cambridge, MA*

Whistler Wave-Plasma Interactions Experiments (S05)

> L. Rooker, K-P. Hu, D. Dahlbom, E. Markwith, A. Tooke, and L.M. Ross, *Boston University, Boston, MA*; R. Pradipta and M-C Lee (Mentor), *Massachusetts Institute of Technology, Cambridge, MA*

Comprehensive Studies of Strong Langmuir Turbulence at HAARP (S06)

> N. Watanabe, C. Balmer, and J. P. Sheerin (Mentor), *Eastern Michigan University, Ypsilanti, MI*; B. J. Watkins and W. A. Bristow, *University of Alaska Fairbanks, Fairbanks, AK*; P. A. Bernhardt and C. A. Selcher, *US Naval Research Laboratory, Washington, DC*; R. L. Moore, *University of Florida, Gainesville, FL*

QPSK Variations for Nonlinear ELF/VLF Generation with Modulated Heating at HAARP (S08)

G. Jin, M. Spasojevic and M. B. Cohen (Mentor), *Stanford University, Stanford, CA*; U. S. Inan, *Stanford University, Stanford, CA and Koç University, Istanbul, Turkey*

Periodic Magnetospheric Probing with HAARP (S09)

V. Harid and M. B. Cohen (Mentor), *Stanford University, Stanford, CA*

Minimizing Harmonic Content in Amplitude Modulation (S10)

S. Naqvi and M. B. Cohen (Mentor), *Stanford University, Stanford, CA*

North/South Asymmetry in ELF/VLF Wave Generation, and Geometric Modulation (S11)

F. Zoghzoghy and M. B. Cohen (Mentor), *Stanford University, Stanford, CA*

Role of Earth-ionosphere Cavity in Frequency Dependence of HAARP ELF Generation (S12)

J. Carpenter, R. Jacobs, M. Webb, Dr. Mark Golkowski (Mentor), *University of Colorado Denver, Denver, CO*

Multiple Site Observations of ELF/VLF Polarizations at Near Distances (S13)

R. Jacobs, J. Carpenter, and Dr. Mark Golkowski (Mentor), *University of Colorado Denver, Denver, CO*

Multiple Site Observations of 'Beamstacking-SEP' (S14)

M. Webb and Dr. Mark Golkowski (Mentor), *University of Colorado Denver, Denver, CO*

ELF/VLF Beam Painting and Time-of-Arrival (S15)

S. Fujimaru and Dr. R. Moore (Mentor), *University of Florida, Gainesville, FL*

HF Experiments on D Region Effects (S16)

J. Langston and Dr. R. Moore (Mentor), *University of Florida, Gainesville, FL*

ELF/VLF Waves Generated Using Multiple Modulated Beams (S17)

T. Wang and Dr. R. Moore (Mentor), *University of Florida, Gainesville, FL*

Dual-beam Heating and ELF/VLF Wave Generation (S18)

D. Agrawal and Dr. R. Moore (Mentor), *University of Florida, Gainesville, FL*

Determination of the Excitation Threshold for Magnetized Stimulated Brillouin Scatter (MSBS) Using the HAARP Facility (S19)

A. Mahmoudian and Dr. W. Scales (Mentor), *Virginia Polytechnic Institute and State University, Blacksburg, VA*; Dr. P. Bernhardt, *US Naval Research Laboratory, Washington, DC*

Experimental Observations of Ion Gyro-harmonic Structures in Stimulated Electromagnetic Emissions (SEE) During Heating Experiments (S20)

A. Samimi and Dr. W. Scales (Mentor), *Virginia Polytechnic Institute and State University, Blacksburg, VA*; Dr. P. Bernhardt, *US Naval Research Laboratory, Washington, DC*

Heater Beam Angle Effect on Stimulated Brillouin Scatter in a Magnetized Ionospheric Plasma (S21)

H. Fu and Dr. W. Scales (Mentor), *Virginia Polytechnic Institute and State University, Blacksburg, VA*; Dr. P. Bernhardt, *US Naval Research Laboratory, Washington, DC*

Investigation of Upshifted Emission Lines in the SEE Spectra for Second Gyroharmonic Heating (S22)

M. Bordikar and Dr. W. Scales (Mentor), *Virginia Polytechnic Institute and State University, Blacksburg, VA*; Dr. P. Bernhardt and Dr. S. Briczinski, *US Naval Research Laboratory, Washington, DC*

Observation of Ionosphere Scintillation on GPS and GLONASS Measurements (S23)

J Triplett, S. Taylor, R. Wolfarth, and Dr. J. Morton (Mentor), *Miami University, Oxford, OH*

4. Summary and Concluding Remarks

Beginning in July 2000, HAARP has joined with the University of Alaska, Fairbanks to conduct a comprehensive summer learning activity aimed at Graduate level students. Until 2008, this Polar Aeronomy and Radio Science (PARS) Summer School was held annually with a split program of activities including a week of lectures and site visitations in Fairbanks followed by a short 4 day campaign at the HAARP Research Station. In 2009, HAARP and UAF jointly agreed to convene the traditional PARS Summer School only on a biennial basis with a Summer Student Research Campaign (SSRC) substituted during the off-years. While the SSRC would not include the concentrated lecture program at UAF, it would increase the amount of time available for research at the HAARP facility.

Organization efforts for the 2011 SSRC began immediately following the decision by AFRL program management in early May 2011. The organization for the campaign was handled by NorthWest Research Associates with administrative assistance from the UAF. An initial announcement for the SSRC was distributed via e-mail on 17 May to a list of scientists who had participated in previous PARS summer schools. This announcement requested responses (including experiment proposals) by 25 May. Since all of the received responses were scientifically sound and because the number of responses was within the budgetary goal, all of the applicants were accepted. A campaign schedule was developed from information contained in the proposals and posted to the campaign website. The schedule was updated several times up to and throughout the campaign.

The 2011 SSRC was conducted from 18-27 July 2011 at the HAARP Facility in Gakona, Alaska. The participants included 26 students and 13 mentors or other visiting scientists representing 11 universities or government laboratories. There were 22 unique student experiments covering a diverse range of ionospheric and radio science topics including generation of ELF waves, comprehensive studies of SEE emissions and processes, generation of acoustic gravity waves, and evaluation of modulation techniques to improve the data throughput of ionospherically generated ELF signals for communication purposes.

The total high-power transmitter time allocated to the students was 77.5 hours which provided an average time per student experiment of approximately 3.5 hours. Universally, the participating students were well-prepared in the planning and execution of their research. In many cases, students who had participated in previous PARS or SSRC campaigns demonstrated an ability to adapt their experiment to changing environmental conditions. In all cases, a strong and intensive collaboration was evident between students and their accompanying mentor as well as with other scientists present at the facility.

As a partial substitute for the intensive lecture program of the PARS summer school, the 2011 SSRC included daily meetings set up to provide a briefing on facility status and expected space weather conditions followed by a period where the assembled group could present interim results and receive comments and suggestion s from others and ending with a presentation or tutorial by one of the visiting scientists. The goal of the results-sharing session was to promote the concept of collaboration among the students as an introduction to their potential roles as participants in future full-scale HAARP campaigns. The success of this aspect of the SSRC was very evident and most gratifying.

Comments received from the participants indicated the increased time made available for research was instrumental in yielding positive results that were of high enough quality for journal publications or conference papers. It is quite interesting to observe the progression in academic maturity and familiarity with conducting research for several of the students who had been attendees at prior PARS or SSRC activities. Several returning students have included their research during these summer experimental campaigns as part of or as the focus of their Ph.D. dissertations.

The HAARP facility, including the high power HF transmitter and phased array antenna along with all of its installed diagnostic instruments performed flawlessly with no interruptions during the campaign period. The HAARP facility staff is to be commended for ensuring that the heater and diagnostic equipment was a state of 100% availability at the beginning of each campaign day and the operations staff once again demonstrated the inherent flexibility and usability of HAARP by responding regularly and in a timely manner to requests for experimental changes in real time. The 2011 SSRC was a success, meeting its academic and experimental goals while simultaneously providing a stimulating experience for all of its participants.

Bibliography

Kennedy, E. J., J. A. Secan, and A. L. Snyder (2012), HAARP 2011 Summer Student Research Campaign Student Summary Reports, *NWRA-12-RS464*, NorthWest Research Associates, Inc., Redmond, WA.

Appendix:
Geophysical Conditions During the Campaign Interval

List of Figures

This appendix provides graphical information characterizing the geophysical conditions during the period July 19-27, 2011 which encompassed the experimental portion of the 2011 Summer Student Research Campaign. The figures are as follows:

Figure A1. An overview of the geophysical conditions observed during the complete 2011 SSRC activity using instruments installed at the HAARP Research Station. The top chart shows data from the flux gate magnetometer, and the bottom chart shows data from the 30 MHz riometer. The period of the campaign is indicated by the blue horizontal arrow. The chart shows unsettled or disturbed conditions were observed at the beginning of the period with generally good conditions thereafter.

Figures A2 through A5. Magnetometer observations from the University of Alaska Geophysical Institute Magnetometer Array, which provide a more detailed view of the variations in the geomagnetic field over Alaska during the campaign. Note that data were available from only three instruments in the array during the campaign interval.

Figures A6 through A9. Data from the HAARP 30 MHz riometer for the campaign period.

Figures A10 and A11. F2-region critical frequency (f_oF2) from the HAARP Digisonde for the campaign period.

Figures A12 and A13. E-region critical frequency (f_oE) from the HAARP Digisonde for the campaign period.

Figures A14 and A15. Absolute vertical Total Electron Content (TEC) derived from GPS signals from the Ashtech Z-Eurocard receiver installed in the HAARP GPS Ionospheric Observing System (GIOS) instrument for the campaign period. The top panel in each figure shows the TEC, and the bottom panel the Ionospheric Penetration Point (IPP) latitude for the measurements. The color-coding in both panels indicates the GPS satellite tracked. The solid and dashed black lines indicate TEC estimates from the TEC model coefficients in the GPS navigation data stream.

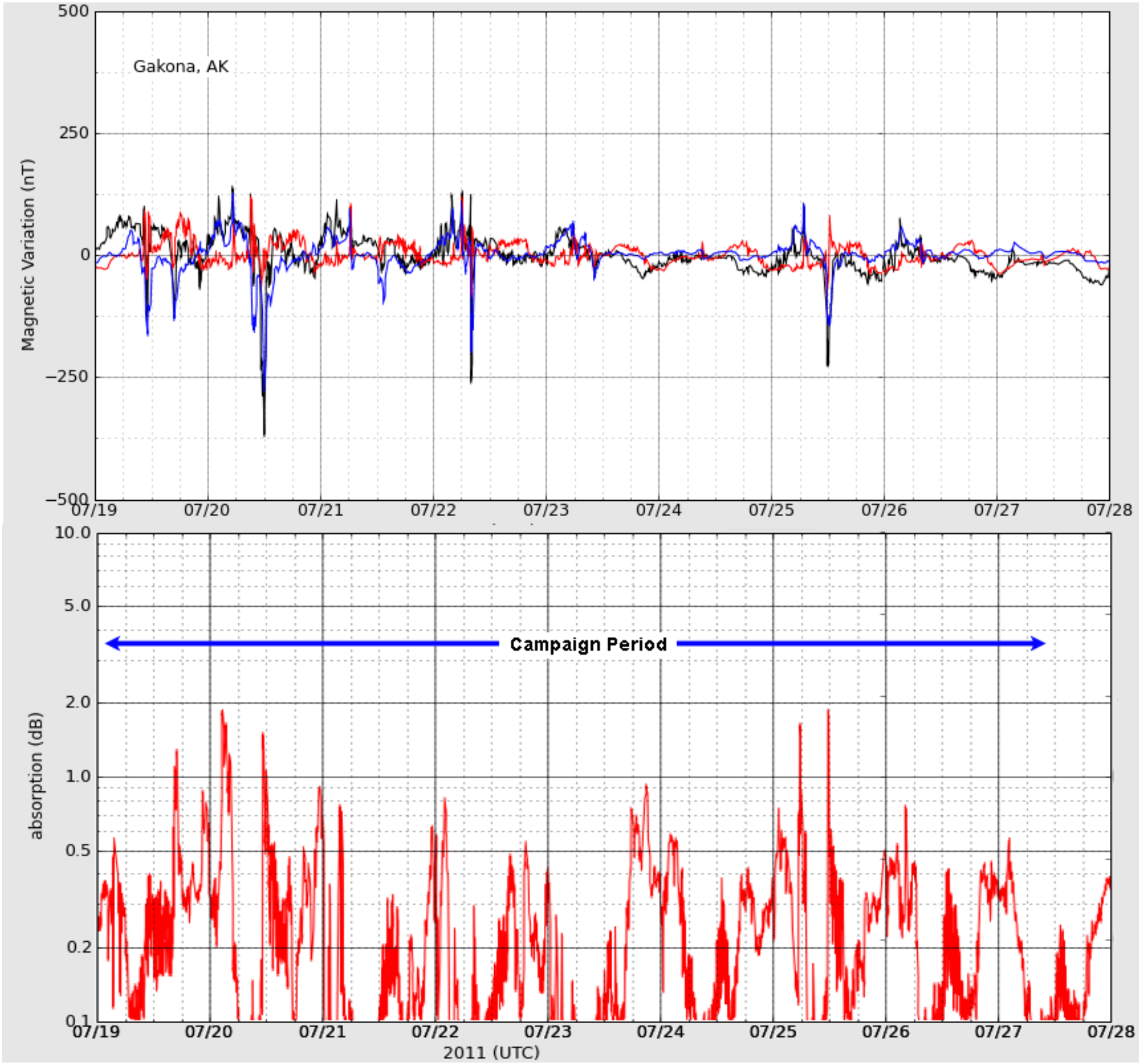


Figure A1. Overview of the geophysical conditions observed during the complete 2011 SSRC activity using instruments installed at the HAARP Research Station.

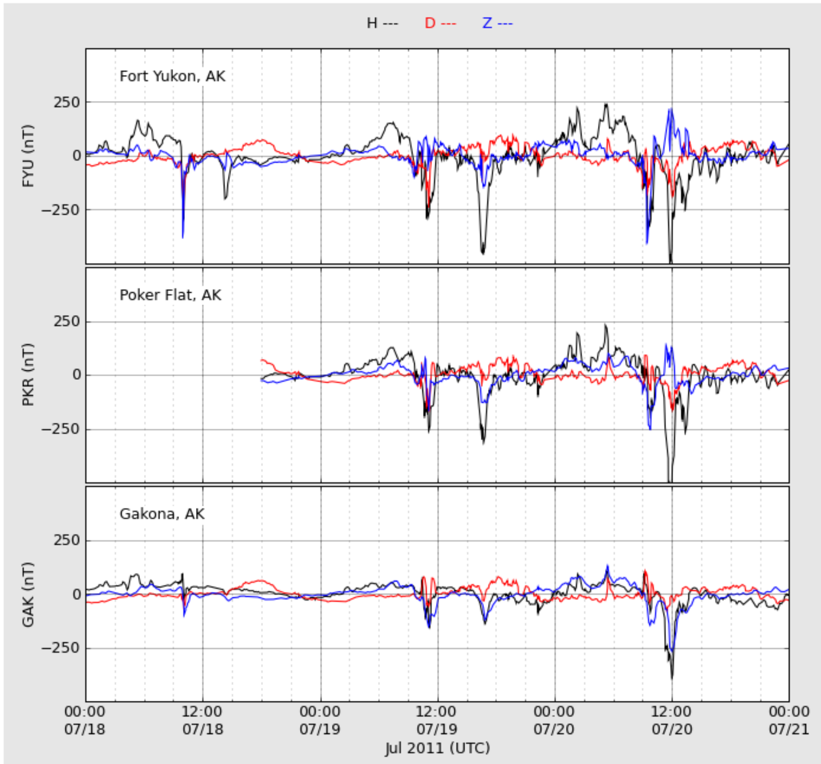


Figure A2. Data from the University of Alaska Geophysical Institute Magnetometer Array for 18-21 July 2011.

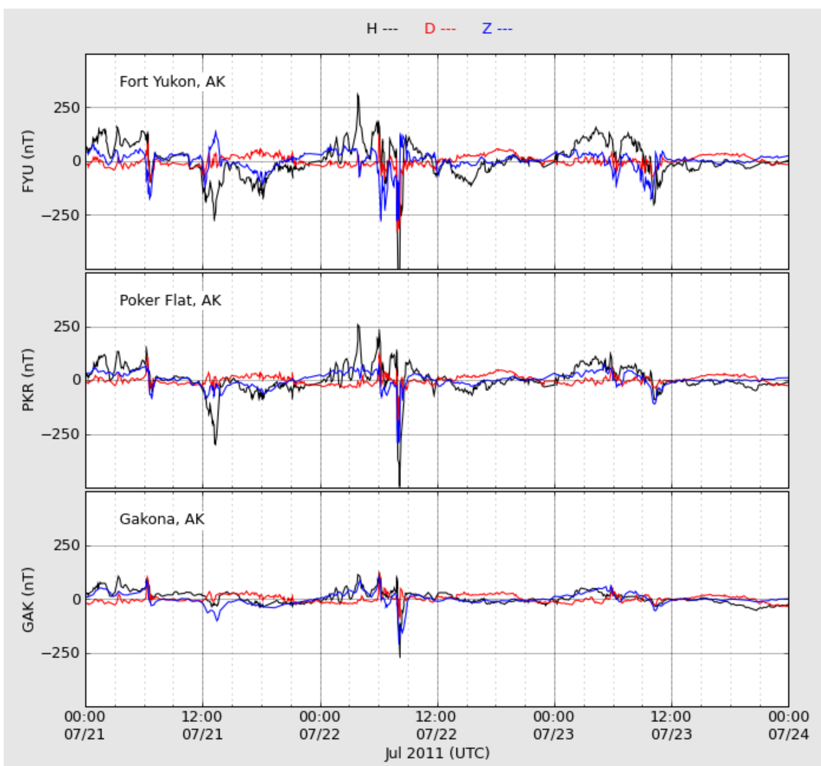


Figure A3. Data from the University of Alaska Geophysical Institute Magnetometer Array for 21-24 July 2011.

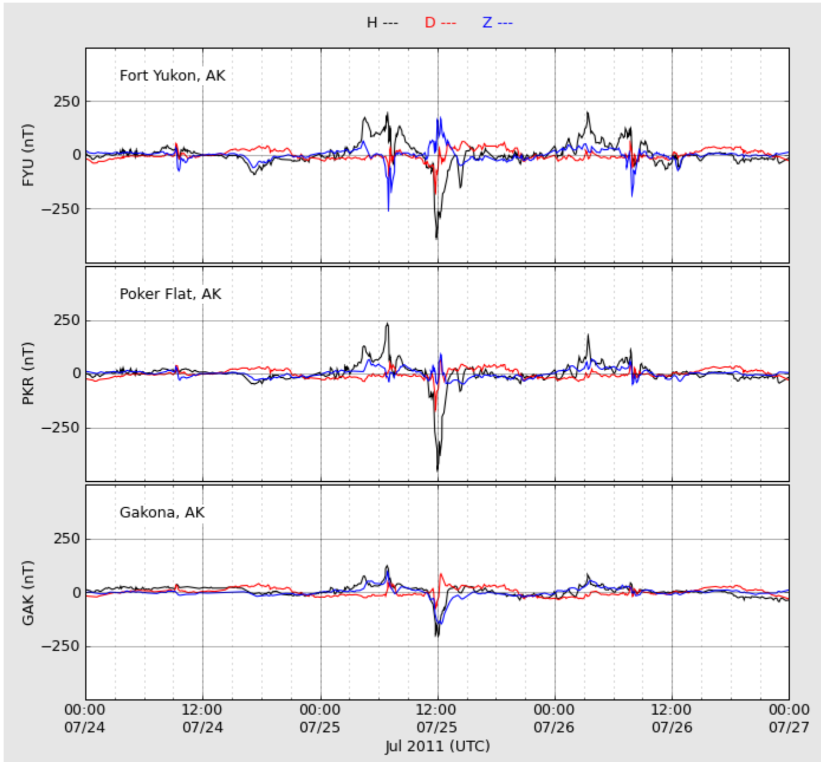


Figure A4. Data from the University of Alaska Geophysical Institute Magnetometer Array for 24-27 July 2011.

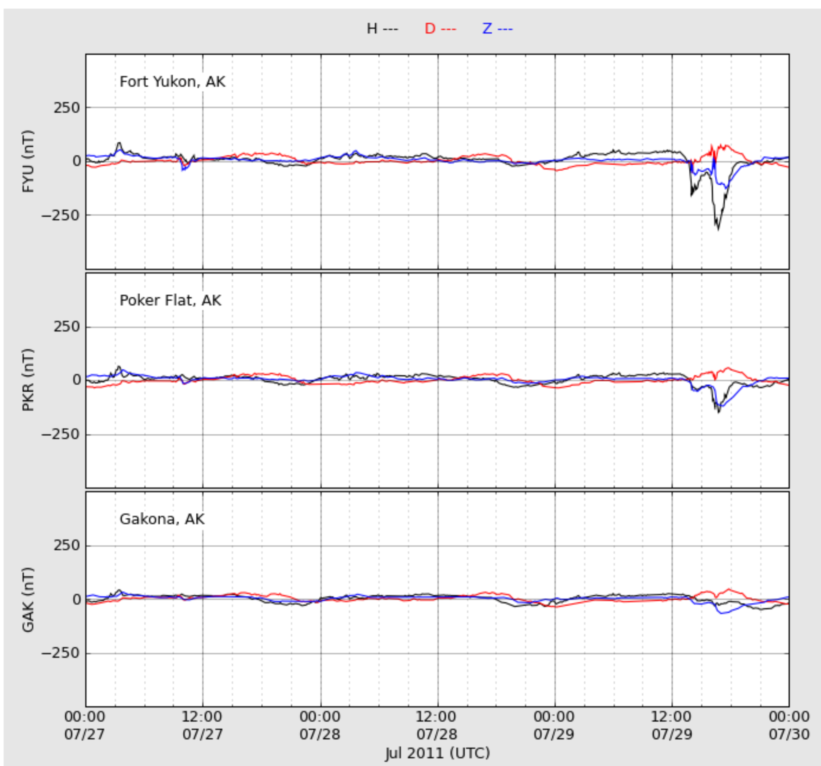


Figure A5. Data from the University of Alaska Geophysical Institute Magnetometer Array for 27-30 July 2011.

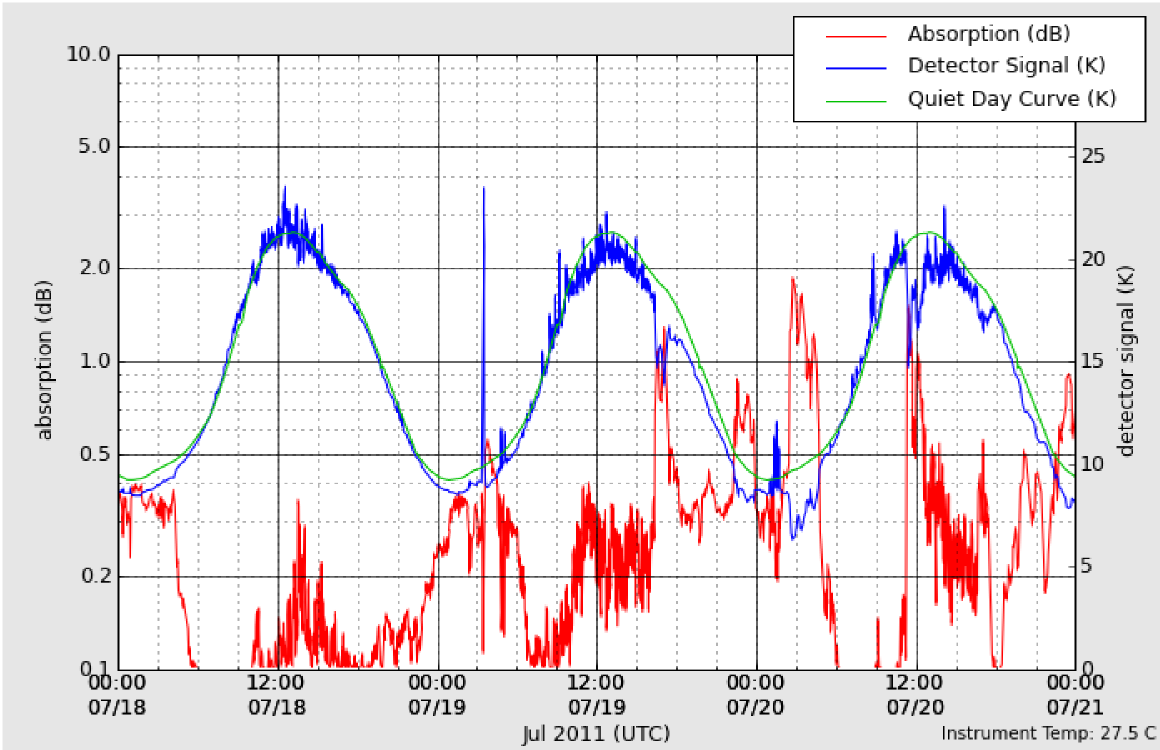


Figure A6. Data from the HAARP riometer for 18-21 July 2011.

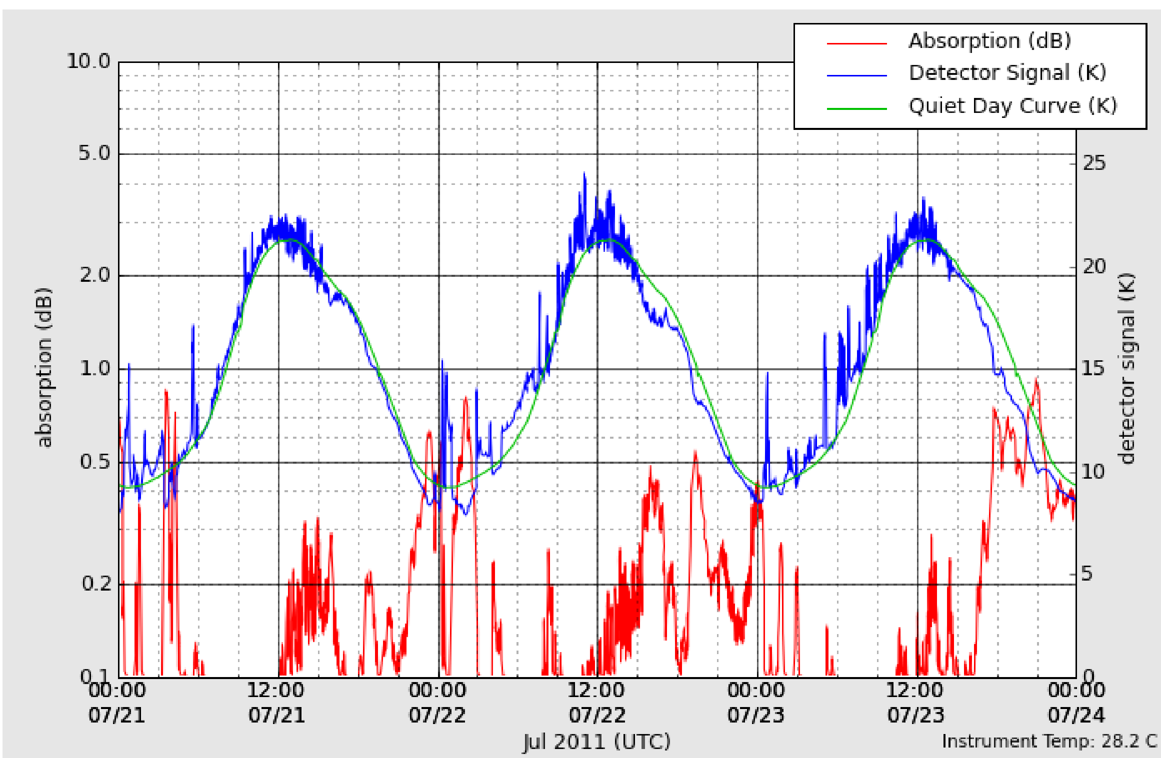


Figure A7. Data from the HAARP riometer for 21-24 July 2011.

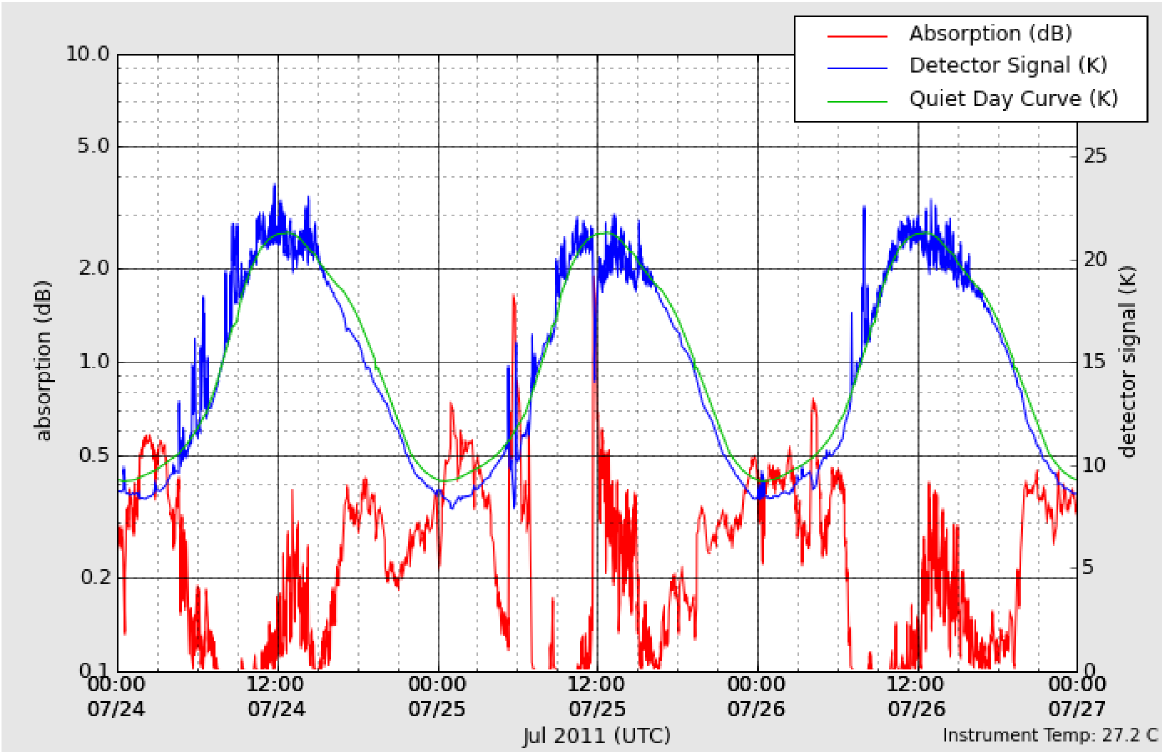


Figure A8. Data from the HAARP riometer for 24-27 July 2011.

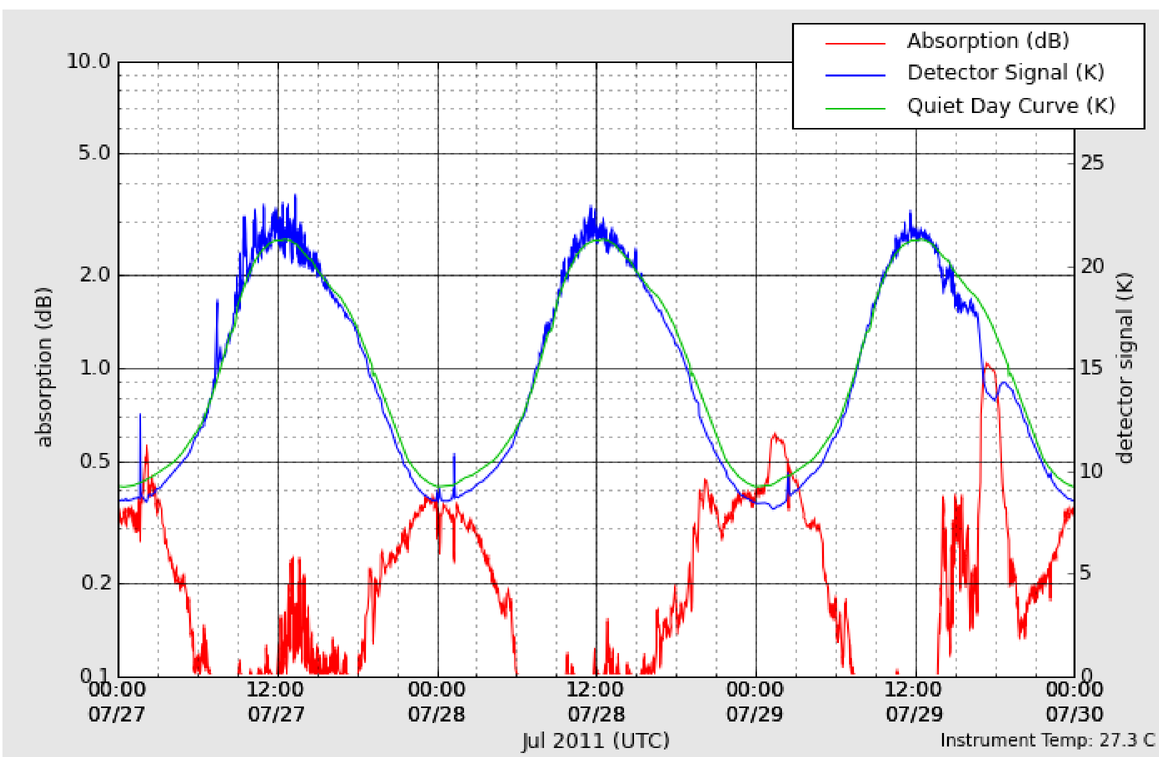


Figure A9. Data from the HAARP riometer for 27-30 July 2011.

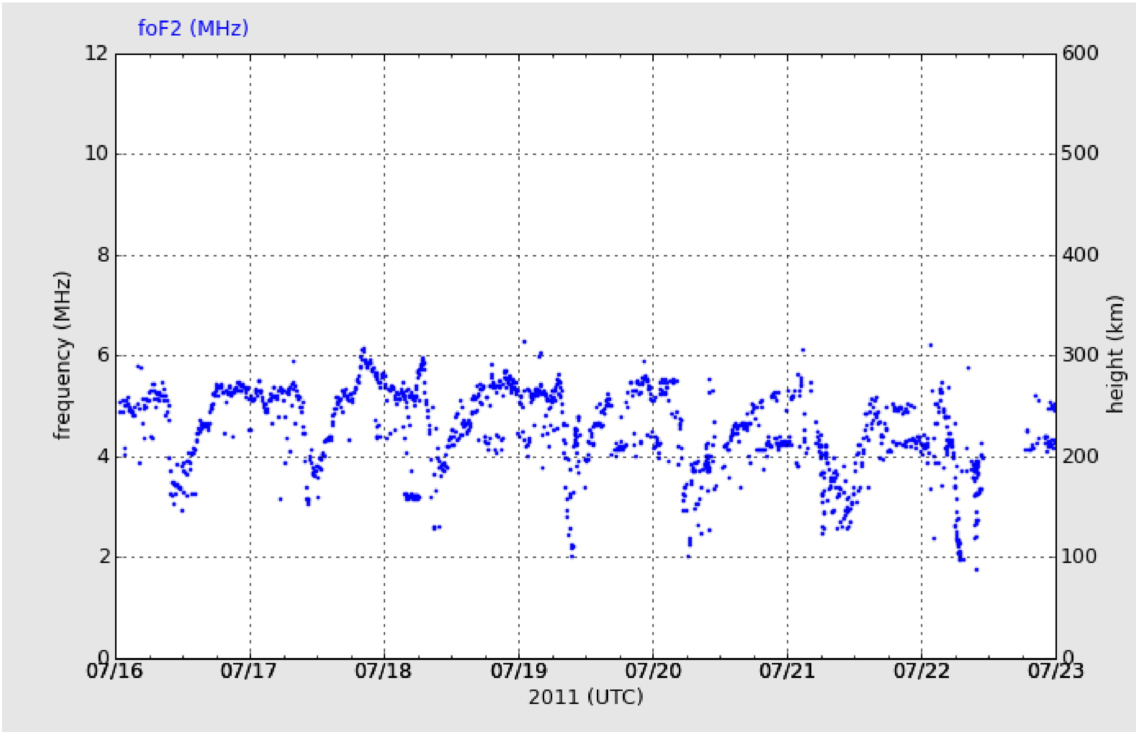


Figure A10. Data from the HAARP Digisonde for 16-23 July 2011 showing the observed F2-region critical frequency (f_oF2).

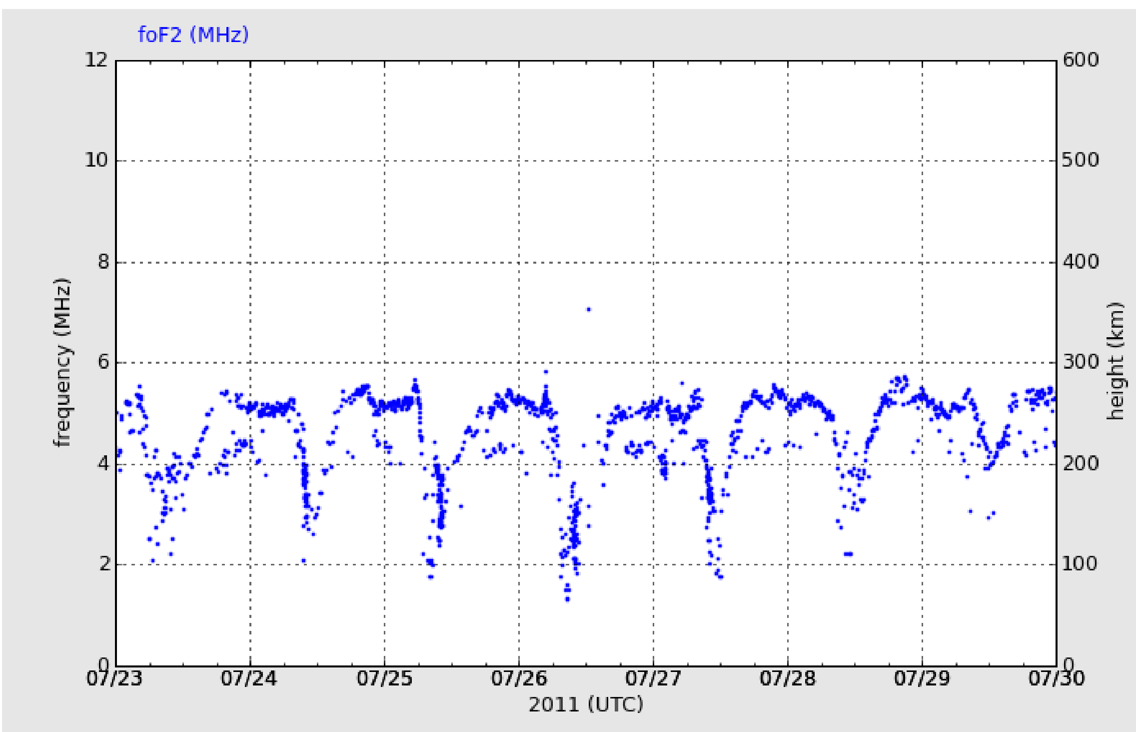


Figure A11. Data from the HAARP Digisonde for 16-23 July 2011 showing the observed F2-region critical frequency (f_oF2).

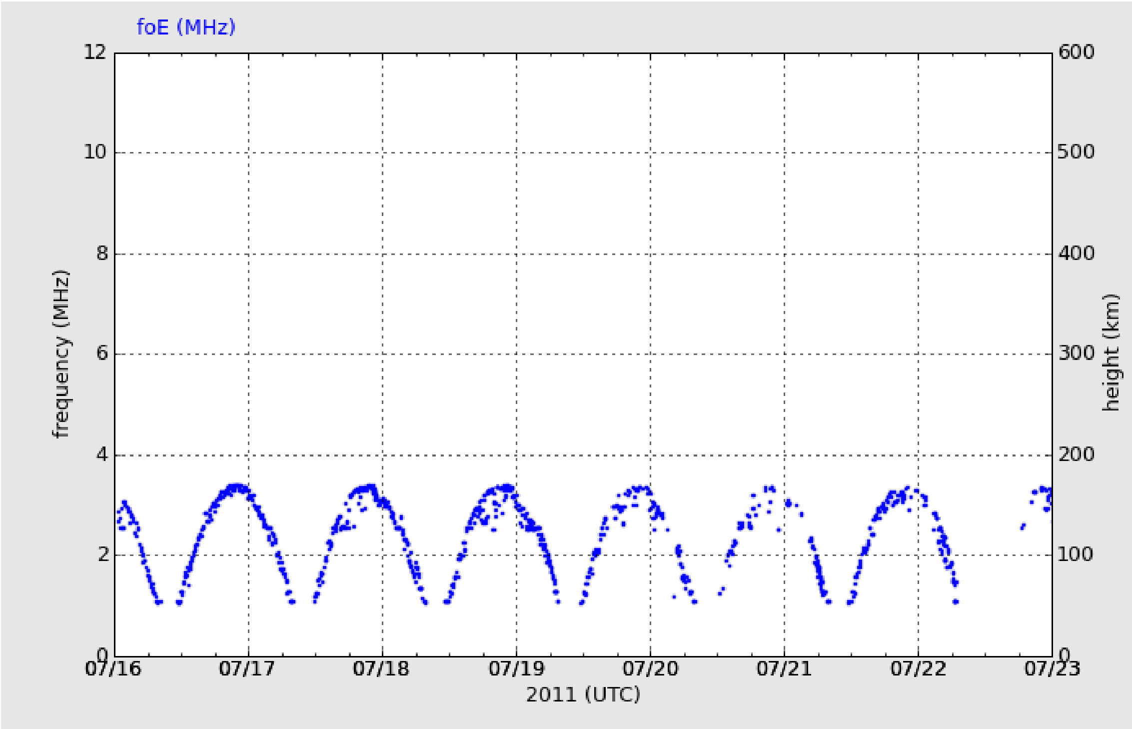


Figure A12. E-region critical frequency f_oE from the HAARP Digisonde for 16-23 July 2011.

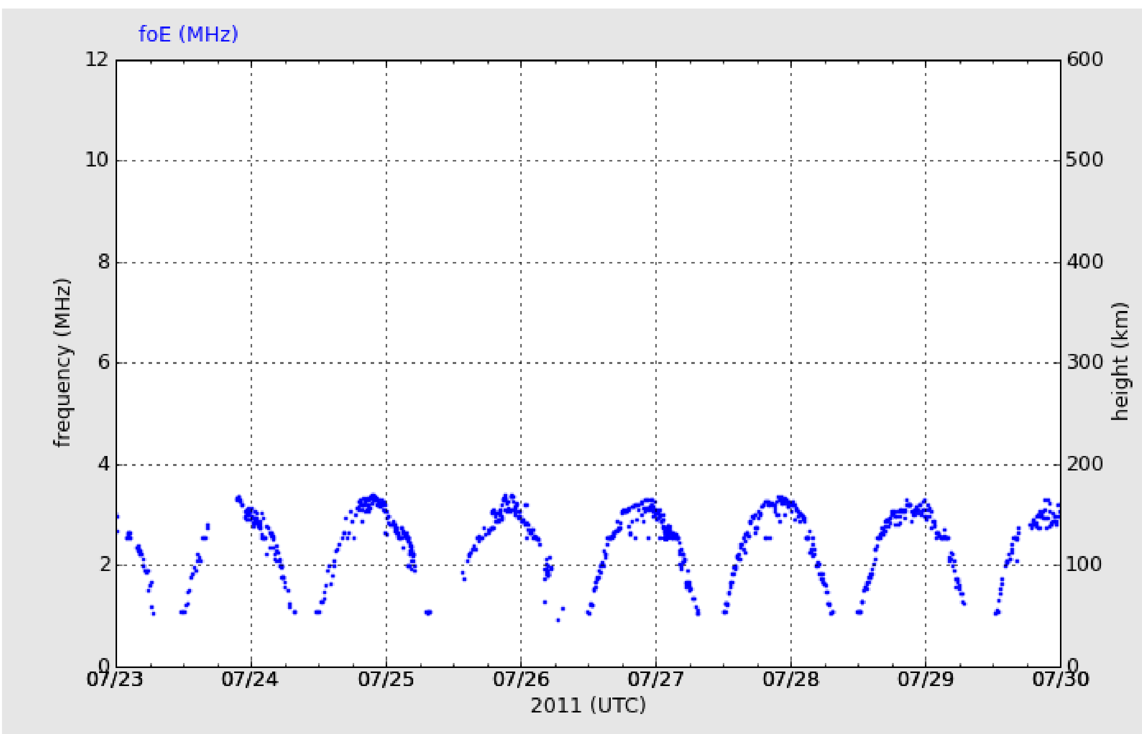


Figure A13. E-region critical frequency f_oE from the HAARP Digisonde for 23-30 July 2011.

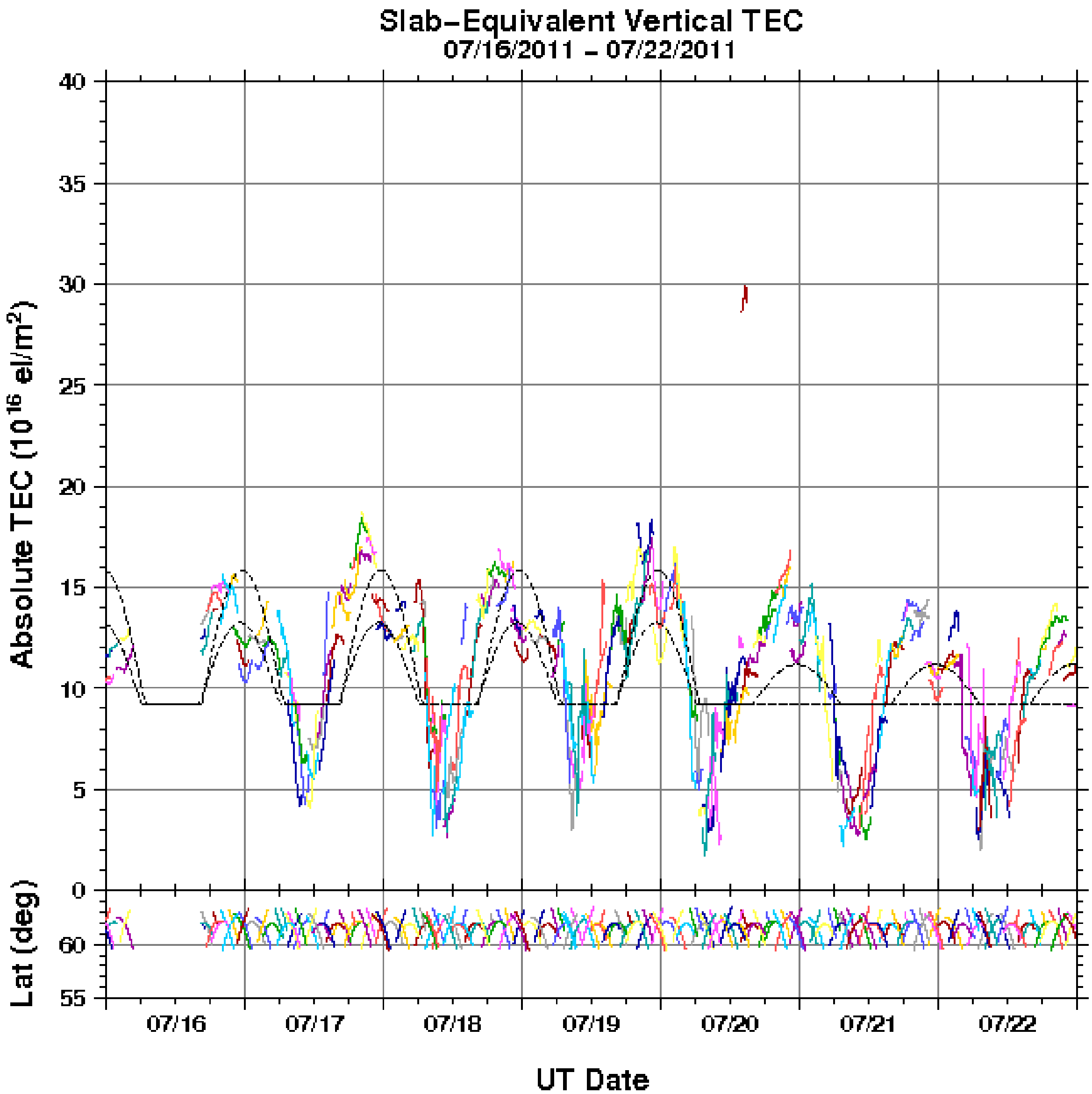


Figure A14. Absolute vertical Total Electron Content for the period for 16-22 July 2011.

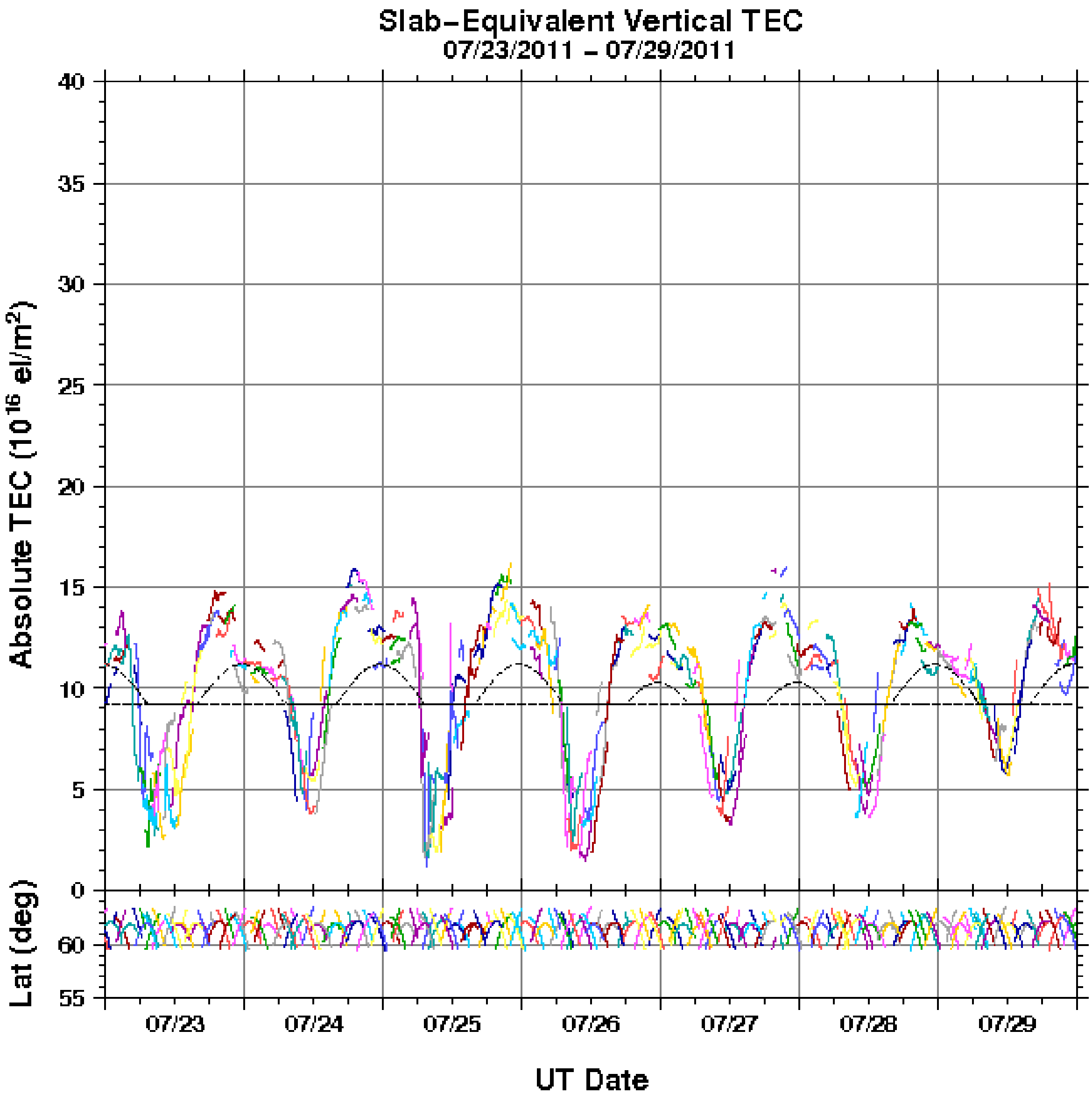


Figure A15. Absolute vertical Total Electron Content for the period for 23-29 July 2011.

List of Symbols, Abbreviations, and Acronyms

AFAI	Artificial Field Aligned Irregularities
AFRL	Air Force Research Laboratory
AMISR	Advanced Modular Incoherent Scatter Radar
BDM	Broad Down-shifted Maximum
BUM	Broad Up-shifted Maximum
DM	Down-shifted Maximum
EIC	Electrostatic Ion Cyclotron (wave)
EISCAT	European Incoherent Scatter Scientific Association
ELF	Extremely Low Frequency (Frequencies in the range 3 Hz - 3 kHz)
eV	Electron volt
foF2	Critical frequency (O-mode) of the F_2 layer (MHz)
f_0E	Critical frequency of the E layer (MHz)
FAI	Field-Aligned Irregularities
FM	Frequency Modulation
GIOS	NWRA GPS Ionospheric Observing System software
GLONASS	Global Navigation Satellite System
GPS	Global Positioning System
HAARP	High-frequency Active Auroral Research Program
HF	High Frequency (Frequencies in the range 3-30 MHz)
HFPL	HF-induced Plasma Line
IA	Ion Acoustic
IPP	Ionospheric Penetration Point or Inter-Pulse Period
IRI	Ionospheric Research Instrument
ITS	Ionospheric Tomography System
K	Kelvin (degrees)
kHz	Kilohertz (10^3 cycles/seconds)
kW	Kilowatt (10^3 watts)
L-band	Radio frequency band covering 1.0 GHz to 2.0 GHz (nominal)
LH	Lower Hybrid
LOS	Line of Sight
MHz	Megahertz (10^6 cycles/seconds)
MSBS	Magnetized Stimulated Brillouin Scatter

MUIR	Modular UHF Ionospheric RADAR
NC	Narrow Continuum
NIMS	Navy Ionospheric Monitoring System
NLDN	National Lightning Detection Network
NRL	Naval Research Laboratory
NWRA	NorthWest Research Associates
ONR	Office of Naval Research
OPL	Out-shifted Plasma Line
PARS	Polar Aeronomy and Radio Science
PCA	Polar Cap Absorption
PDI	Parametric Decay Instability
PRN	Pseudo-Random Noise (GPS identification signature)
PSK	Phase Shift Keying
QPSK	Quadrature PSK or Quaternary PSK
rms, RMS	root mean square
RTI	Range Time Intensity
S_4	Ionospheric intensity scintillation index (non-dimensional)
S-band	Radio frequency band covering 2.0 GHz to 4.0 GHz (nominal)
SEE	Stimulated Electromagnetic Emission
SNR	Signal to Noise Ratio
sps	samples per second
SRII	SRI International
SSRC	Summer Student Research Campaign
SuperDARN	Super Dual Auroral Radar Network
TE	Transverse Electric (wave mode)
TEC	Total Electron Content (electrons/m^2)
TEM	Transverse Electromagnetic (wave mode)
TM	Transverse Magnetic (wave mode)
TOA	Time of Arrival
UH	Upper Hybrid
UHF	Ultra High Frequency radio band (300 MHz – 3 GHz)
ULF	Ultra Low Frequency radio band
UML	University of Massachusetts at Lowell
UMLCAR	University of Mass Lowell, Center for Atmospheric Research

UPS	Uninterruptible Power Source
VHF	Very High Frequency radio band (30 MHz – 300 MHz)
VLF	Very Low Frequency radio band (3 kHz – 30 kHz)
VTEC	Vertical (or equivalent vertical) TEC (el/m^2)

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